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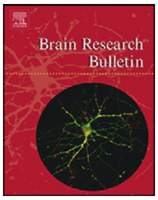

Research report

Decomposing metaphor processing at the cognitive and neural level through functional magnetic resonance imaging

Valentina Bambini[a,*], Claudio Gentili[b], Emiliano Ricciardi[c], Pier Marco Bertinetto[a], Pietro Pietrini[c]

[a] Laboratorio di Linguistica "G. Nencioni", Scuola Normale Superiore, Piazza dei Cavalieri 7, I-56126 Pisa, Italy
[b] Unit of Clinical Psychology, AUO Pisa, Department of Psychiatry, Neurobiology, Pharmacology and Biotechnologies, University of Pisa, Via Roma 67, I-56126 Pisa, Italy
[c] Laboratory of Clinical Biochemistry and Molecular Biology, Department of Experimental Pathology, Medical Biotechnologies, Infectivology and Epidemiology, University of Pisa, Via Roma 67, I-56126 Pisa, Italy

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ABSTRACT

Prior neuroimaging studies on metaphor comprehension have tended to focus on the role of the right hemisphere, without reaching consensus and leaving aside the functional architecture of this process. The present work aimed to break down metaphor comprehension into its functional components. The study rationale is two-fold: on the one hand, the large-scale network model as emerging in cognitive neuroscience led us to a consideration of metaphor as supported by a distributed and bilateral network; on the other hand, we based on the accounts of figurative language put forward in pragmatics and cognitive science to postulate a decomposition of such a network into multiple sub-systems. During scanning, participants implicitly processed metaphorical (familiar and unfamiliar) and non-metaphorical passages, while being explicitly involved in an adjective matching task to be performed after reading the target passages. Several regions showed greater activity to metaphors as compared to non-metaphors, including left and right inferior frontal gyrus, right superior temporal gyrus, left angular gyrus, and anterior cingulate. This pattern of activations, markedly bilateral, can be decomposed into circumscribed functional sub-systems mediating different aspects of metaphor resolution, as foreseen in the pragmatic and cognitive literature: (a) the conceptual/pragmatic machinery in the bilateral inferior frontal gyrus and in the left angular gyrus, which supports the integration of linguistic material and world knowledge in context; (b) the attentional component in the anterior cingulate and prefrontal areas, which is set to monitor and filter for the relevant aspects of context and for the appropriate meanings; (c) the Theory of Mind system along the right superior temporal sulcus, which deals with the recognition of speakers' communicative intentions and is more extensively activated by unfamiliar metaphors. The results have several implications for the field of neuropragmatics, especially on the neuropsychological side and on the right hemisphere hypothesis.

1. Introduction

In verbal communication, sentences are usually underspecified with respect to what speakers intend to convey. Since long pragmatics has brought to the fore the discrepancy between linguistically encoded meaning and communicated meaning and has pointed to a number of cases where this gap is especially evident: conversational implicatures, indirect speech acts and figurative uses, among which metaphor [46]. Very commonly in linguistic usage words happen to depart from encoded meanings to assume metaphorical nuances: it has been estimated that there are about 5 metaphors (of different types) for every 100 words of text [90]. Relative to non-figurative meanings and context being equal, the comprehension of metaphors posits additional processing costs, which are nevertheless compensated by cognitive benefits in terms of communicative effectiveness [82]. Mastering metaphor resolution thus represents an important aspect of speakers' pragmatic competence, subject to specific developmental paths and possibly decay and damage [107]. The last three decades have seen a marked increase in the number of studies concerned with characterizing metaphor from the point of view of the underlying neural substrate, starting with clinical reports and then expanding to functional exploration of the healthy brain [96]. However, this literature has been mainly debating over the role of the right hemisphere, leaving aside the neurofunctional architecture of metaphor. In this paper we present an fMRI study devoted to break down metaphor comprehension into its functional components. It will be argued that the large-scale network model as imposing itself in cognitive neuroscience, coupled with hints coming from pragmatic and cognitive theories of metaphor, provides us with the appropriate framework to capture the essence of metaphor processing in terms of its neurofunctional architecture.

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* Corresponding author. Tel.: +39 050 509729; fax: +39 050 563513.
E-mail address: v.bambini@sns.it (V. Bambini).

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1.1. Neuropsychological findings on metaphor comprehension

The question of paramount interest in the neuropsychological literature on metaphor is the role of the right hemisphere. Back in the 1980s and up to the 1990s the dominant view was that the right hemisphere is in charge of all language tasks that require the listener to recruit information from background knowledge or to appreciate the relationship between a word/utterance and its context of use [54]. Metaphor and other non-literal uses seemed to fall squarely within this umbrella, and early studies supported such a view. Using a picture-matching task, Winner and Gardner [112] reported a tendency in the right hemisphere damaged group to match metaphorical sentences with literal pictures (40%), which was not present in the left hemisphere damaged and in the control groups. Other studies employing word triad relatedness paradigm offered further support to the right hemisphere hypothesis [16].

More recent literature has cast doubts on those early results. The most consistent objection concerns the possible confounding effects of right hemisphere visuo-spatial deficits in determining low performances in the picture-matching task. It went quite unnoticed that Winner and Gardner ran a verbal task, along with the pictorial one, where the same right hemisphere damaged patients who made errors in the picture-matching task performed correctly. Rinaldi et al. [93] revamped the combination of picture-matching and verbal tasks, while carefully checking and ruling out visuo-spatial deficits. They replicated Winner and Gardner' results in both tasks, and proposed that the right hemisphere damaged patients have difficulties in operations that require the integration of different representation modalities, rather than in metaphor comprehension *per se*. Another critical aspect across the early neuropsychological literature is the poor consideration of the fact that metaphors have a career and evolve from brand-new expressions to lexicalized idioms: processing is likely to evolve accordingly [14]. Traditional studies tended to employ conventional metaphorical expressions, while recent literature has shown that idioms, conventional metaphors and novel metaphors exhibit distinct patterns of disruptions [2,83].

In the last years, investigations have adopted more refined verbal tasks and have expanded to clinical populations other than patients with damages to the right hemisphere: deficits in metaphor comprehension may surface in case of lesions to the left hemisphere [39], Alzheimer's disease [2,83], Parkinson's disease [78], autism [50,81], William's syndrome [3] and schizophrenia [53]. As a result, a number of different explanations are being proposed, varying according to the profiles of the clinical populations, e.g., pointing to executive functions for dementia and to Theory of Mind for autism. It has been argued that for metaphor – and for pragmatic disorders in general – it is plausible that similar disruptions at the behavioral level are caused by different kinds of cognitive deficits [66,102]. We will further consider the neuropsychological literature in the discussion (Section 4.3). What concerns us here is that the body of clinical findings does not easily reconcile with the right hemisphere hypothesis – at least when intended in the original, clear-cut form –, and that the current trend is to leave aside possible differential contributions of each hemisphere and to focus on the different cognitive systems that may in turn undermine metaphors processing in specific pathological conditions.

1.2. Neuroimaging findings on metaphor processing

The role of the right hemisphere has been a crucial topic also in the brain imaging literature on metaphor. Although specifying hemispheric dominance might seem the type of issue that PET/fMRI studies are well placed to address, results are equivocal: brain activity has been reported in the right hemisphere only, in the left hemisphere only, not without cases of bilateral patterns (see [97] for a summary table). Bottini et al. [12] pioneered the field with a PET study where participants were asked to perform a plausibility judgment on either literal or metaphorical English sentences. Metaphorical sentence judgments produced greater activation in several areas of the right hemisphere, most notably in inferior frontal gyrus, pre-motor cortex, midtemporal gyrus, precuneus, and posterior cingulate.

Despite its innovation and the high plausibility of the anatomo-functional correlations proposed, the study conducted by Bottini et al. exhibits a number of critical aspects. The most evident issue is the unmatched level of complexity between literal and metaphorical stimuli [11,70]. Similar considerations have led recent investigations to apply more tightly controlled experimental materials, producing radically different results in terms of hemispheric distribution. Rapp et al. [91] tested simple German literal and metaphorical sentences differing only in the last word and asked participants to perform a valence task. Results showed exclusively left hemisphere activations, specifically in the left inferior frontal gyrus (see [92] for further analysis on the same dataset). A study run by Stringaris et al. [105] on similar materials with a meaningful decision task confirmed the left lateralization of metaphor processing, pointing to activations in the left inferior frontal gyrus and the underlying left thalamus. Similar emphasis of the role of the left inferior frontal gyrus is posited by Shibata et al. [98].

In contrast with the above mentioned left-sided findings on metaphorically used nouns in sentences, another group of studies on metaphorical two-word expressions reported bilateral but predominantly right-sided patterns of activations. Mashal et al. [68,69] especially pointed to the role of the right homologue of Wernicke's area in processing novel metaphoric word pairs. Another study employing TMS confirmed the special role of the right posterior superior temporal gyrus [89], a role that might be reduced over the course of conventionalization (see [67], where such course was accelerated by means of repeated exposure). In harmony with these findings, when conventional metaphors are used, activations are limited to the left hemisphere, both in the case of word triads and in the case of utterances [64 and 33, respectively].

There is also fMRI evidence in favor of a more distributed bilateral configuration: see [1] on conceptual metaphors in Chinese and [73] on adjectives carrying conventional metaphorical meanings (with a more widespread distribution in older than in younger participants). Bilaterality finds further support in ERP data coupled with hemifield presentation [26].

One potential basis for the conflict in the PET/fMRI literature over the localization of metaphor comprehension may lie in the heterogeneity of the experimental paradigms, especially in the tasks. This aspect has been specifically addressed in [113] by comparing metaphor processing during different tasks. When engaged in the valence task, participants' comprehension of metaphor seems to especially depend on bi-frontal regions, while, when engaged in the imageability task, activations are observed in the bilateral superior and middle temporal gyri. Also the recruitment of the right hemisphere has been claimed to depend on the type of task, being especially involved when participants are required to search for semantic relations evoked by the metaphors and not simply to extract meaning [104]. Another possible source of cross-study inconsistency may lie in the different complexity exhibited by metaphorical expression. Schmidt and Seger [97] aimed at ascertaining this domain, by disentangling figurativity from familiarity and difficulty. Each of these factors seems to recruit regions in the right hemisphere, which thus cannot be claimed to be sensitive to metaphoricity *per se*. Together, these recent findings contribute to sketch a complex picture, where the neural correlates of metaphor comprehension turn out to be deeply affected by other processing demands (related to the task and to the complexity of the metaphor), but essentially do not solve the right vs. left hemisphere *querelle* concerning metaphor processing in itself, independently on extra processes.

1.3. Rationale and aims of the study

Faced with the abundant though discordant literature described in the above sections, we undertook this study to shed new light on the neural basis of metaphor comprehension. Rather than focusing on the role of the right vs. left hemisphere, we were interested in disentangling the additional cognitive demands that, context being equal, metaphor brings to literal comprehension, based on the main hypothesis that a complex cognitive function such as metaphor comprehension involves a vast array of sub-functions and that a distributed brain network is likely to result from such a high-order interplay, presumably in a bilateral fashion. The remainder of this section spells out in more detail the hypothesis of a bilaterally distributed network, by listing the putative components of such a network based on the pragmatic and cognitive literature (Section 1.3.1) and then by sketching the main tenets of a new fMRI experiment designed to isolate these components (Section 1.3.2).

1.3.1. Toward a functional network model of metaphor comprehension

Cognitive neuroscience has been emphasizing that a cognitive function does not involve a brain region specialized for that function but rather a concerted activity of regions that perform different sub-components of that function [15,75]. This organization especially holds for high-order cognitive abilities: when processes become more complex, networks become more distributed, as more processes and representations are involved [18]. A superb example is provided by face perception, perhaps the most highly developed visual skill in humans, which is mediated by a core system supporting visual analysis, along with other systems elaborating social aspects of faces, e.g., speech-related information, emotional expressions, etc.: this orchestration of functions results in a distributed neural system comprised of multiple, bilateral regions [51]. Bilateral distribution is indeed a recurrent feature in the large-scale network account: in many cases both sides of the brain have been shown to work in tandem to achieve complex functions, with symmetry in hemispheric distribution varying in relation to the specific task. In this scenario, it is not rare that cognitive abilities traditionally ascribed exclusively to the right hemisphere are nowadays depicted as more widely distributed over the cortex (consider, for instance, the case of mental rotation [76]). The right hemisphere hypothesis is currently declining in favor of bilateral distributed models also for what concerns high-level linguistic processes such as understanding language in context and discourse: see the “parallel networks of discourse pragmatics” [70] and the “extended language networks” [35].

When it comes to metaphor, however, the brain imaging literature has rarely discussed the constellations of activations in light of the functional network account. Rather, prior studies have disputed over the lateralization issue, as illustrated in the previous section, and a clear cognitive decomposition is still missing. Although a functional network account has never been fully worked out for metaphor, hints to that direction can nevertheless be found in pragmatic and cognitive theories of metaphor (mainly along the lines of Relevance Theory and Cognitive Linguistics), which over the last three decades have been proposing and refining psychologically plausible models of metaphor comprehension spanning over language and general cognition. Based on these accounts, it is possible to hypothesize the putative building blocks of the metaphor comprehension process.

(a) *The conceptual component*. A common feature across theories of metaphor is the involvement of the conceptual system. In the framework of Relevance Theory, metaphor is seen as a case of meaning fine-tuning emerging from context-based inferential processes: the result is the constructions of an *ad hoc* concept conveying the communicated meaning [20,110,111]. According to Glucksberg [45], metaphors are class-inclusion assertions whose interpretation involves the construction of more inclusive categories relative to those representing literal meaning. Cognitive Linguistics considers metaphor as a special case of conceptual integration resulting from association and blending among mental spaces [25]. Other authors postulate a conceptual mapping from abstract sources to concrete domains, through embodiment [43,63]. Although very different in terms of the operations involved (inference vs. categorization vs. association), all these approaches postulate that metaphor crucially capitalizes upon the conceptual system, integrating linguistic information (lexical meanings) with knowledge about the world deposited in long term memory.

(b) *The attentional component*. The ability to solve metaphorical expressions relies on bridging word meanings on the one hand and world knowledge and context of use on the other. Pragmaticists have pointed out that a similar integration is achieved through an attentional bottleneck: the system needs to constantly monitor environmental features and access memorized data (word meanings and word knowledge) in order to select information worth bringing together [100]. Moreover, several psycholinguistic accounts of figurative language postulate the activation of alternative meanings, (e.g., the suppression-inhibition model; see [42]), the selection of which is likely to engender attentional control.

(c) *The Theory of Mind component*. Another important suggestion coming from cognitive theorizing on metaphor concerns the involvement of Theory of Mind processes. Following Grice’s intuition, Relevance Theory assumes that speaker’s meaning is prompted by the recognition of the speaker’s communicative intention [99]. Similarly, Cognitive Pragmatics points to intention recognition in interpreting speech acts, with increasing cognitive load from simple to complex speech acts [7]. The Theory of Mind system has been identified as the cognitive substrate supporting intention recognition in communication and social interaction [7,38]. It is likely that, when communication gets figurative, the load on the intention recognition mechanisms increases with respect to the non-figurative equivalent, invoking the involvement of at least some sub-parts of the mind-reading system.

Based on this literature, we hypothesize that the process of metaphor comprehension elicits the three above-mentioned components. Specifically, the engagement of the conceptual system is expected to produce activations in left frontal areas [10], possibly including the right homologues [48]; the monitoring processes are expected to recruit part of the attentional system, which is known to be distributed over the frontal lobes and the cingulate cortex [77]; mind-reading operations are expected to activate part of the Theory of Mind system, which is known to be extended over several areas, among which the superior temporal sulcus (especially posterior) and the medial prefrontal cortex [8,23,37,108]. This interplay of functional components is in turn expected to activate a bilateral network, with bilaterality resulting from the multiplicity of the systems involved, and from the widespread distribution of each of them. The aim of this study is to verify the neurofunctional decomposition described above through fMRI, and to suggest a new perspective on the conflict in the literature on the localization of metaphor processing in the province of either the left or the right hemisphere. Given the utility of going from cognitive models to brain mapping and back, identifying the functional systems involved in metaphor comprehension could also bring new insights in support of either one of the cognitive models of metaphor comprehension.

1.3.2. Experimental design

In the attempt to disentangle the functional components of metaphor processing, we devoted special attention to the creation of a novel experimental paradigm, by introducing a number of modifications relative to prior studies.

The main issue was to focus on metaphor processing independently of other tasks, i.e., to avoid parallel processes such as those introduced in the previous experiments (e.g., valence judgment, meaningfulness judgment, etc.), which might play as confounds and obscure the genuine functional components of metaphor comprehension. Indeed, as noted in. [113], in daily-life communication metaphor processing is likely to be affected by other types of judgments. These are presumably related to the specific communicative situation and embrace the cognitive effects produced by a metaphor, which may range from judgments about the interlocutor's personality to emotional experiences. Here, however, we aimed at leaving aside the variety of meta- and para-linguistic operations that may in turn go with metaphor processing in specific situations to focus on the process of metaphor comprehension *per se*. To this purpose, we were interested in preserving a general feature of ecological figurative language comprehension: when encountered with a metaphor, hearers/readers are unaware of the figurative nature of the linguistic material under elaboration, and solve it unknowingly. In addition, we searched for a low demanding task that could be performed without interferences on the comprehension processes in itself. We ideated an experimental paradigm where participants were not informed that metaphor was the actual focus of the study, a caution that, coupled with a 1:2 ratio between metaphorical and non-metaphorical items, should prevent them from actively (and unecologically) searching for metaphors and that has never been explicitly stated in previous studies. While metaphor comprehension was given as an implicit task, the explicit task consisted in matching each target passage with one out of two adjectives presented after the passage (adjective matching task). Although meta-linguistic and possibly eliciting ancillary strategies, this task was intended to be low-demanding and equal across conditions, keeping possible confounding effects over metaphor processing to minimum.

Another important methodological point was stimulus construction. Drawing on the diffuse idea that the conceptual system is centrally involved in metaphor comprehension, we searched for a solution especially attuned to unveil the conceptual machinery behind the construction of context appropriate meaning. We followed the tradition of studies employing metaphors in sentences rather than in word-pairs: sentence forms are more likely to evoke ecologically valid and task-free processing. As in other fMRI studies [91,105], we focused on the simplest kind of sentential metaphor, in order to avoid possible confounding effects due to structural complexity: we employed metaphors with an underlying structure of the type "X is Y" (e.g., "That lawyer is a shark"), in which – according to traditional terminology – X serves as the so-called metaphor's "tenor" (also known as "topic") and Y serves as the so-called metaphor's "vehicle". However, unlike previous fMRI works, we applied a paired design where metaphors' vehicles were kept constant: each "X is Y" metaphor was paired with a literal structure of the form "Z is Y" (e.g., "That lawyer is a shark" was paired with "That fish is a shark"). In prior experiments, either the design was not paired or the pairs were built upon constant metaphors' tenors (e.g., "That lawyer is a shark" would be paired with "That lawyer is a public defender"). The solution we adopted seems more apt to reveal the cognitive modulation that metaphor is expected to bring on the single lexical unit.

Furthermore, while building the passages, we considered the two major parameters that are known to influence metaphor processing costs, namely familiarity and context. Familiarity is here conceived of as an umbrella notion embracing several parameters of metaphor complexity, among which frequency of the single word, frequency of the metaphorical use of that word, conventionalization and aptness (similar to what Giora [44] calls "salience"). We excluded fully conventionalized metaphors (e.g., "volpe", *fox*, for a smart person), for they have become part of the mental lexicon and are presumably processed differently from creative uses, and we subdivided the stimulus set in familiar and unfamiliar (non-lexicalized) metaphors. We expect the brain network responsible for metaphor comprehension to be modulated accordingly. As for context, we manipulated the linguistic cues available in the ongoing discourse, by displaying each metaphor both in a minimal context and in a supportive context form. The latter type was built as to make so-called metaphor's ground explicit, i.e., the property that bonds the metaphor's topic and the metaphor's vehicle (e.g., "aggressive" as in "That lawyer is really aggressive. He is a shark"). We expect this manipulation to influence the network responsible for metaphor comprehension, with less demanding loads on the conceptual system in the supportive context relative to the minimal context condition.

2. Methods

2.1. Participants

Ten healthy volunteers (5F/5M, mean age 25 ± 1 years) took part in the study. The data of one female participant were excluded from the analyses because of motion artifacts. Due to hardware and software upgrade of the scanner, we had to stop recruiting subjects. All participants were monolingual native speakers of Italian with a high educational level (18 years of schooling on average), right-handed and with normal or corrected-to-normal vision. All subjects received medical, neurological and psychiatric examinations, and laboratory testing, including a structural brain MRI scan exam, to rule out history or presence of any disorder that could affect brain function and development. No subject was taking any psychotropic medication. All participants gave their written informed consent after the study procedures and potential risks had been explained. The study was conducted under a protocol approved by the Ethical Committee at the University of Pisa Medical School (Protocol n. 020850). All participants retained the right to withdraw from the study at any moment.

2.2. Stimuli and task

A total of 200 Italian two-sentence passages built de novo functioned as stimuli. Metaphoricity, as well as the familiarity and the amount of information in the linguistic context were manipulated in a paired design which was built and validated across several steps.

Selection of the nouns to serve as metaphors' vehicles. Nouns were selected in such a way that each could be associated with another noun once metaphorically and once literally (e.g., "libellula", *dragonfly*, was associated once with "ballerina", *dancer*, and once with "insetto", *insect*) on the basis of a property that was appropriate as metaphor's ground and worked properly in the literal association (e.g., "aggraziata", *graceful*). 68 associations were constructed. The metaphorical versions were classified half as familiar (e.g., "libellula"-"ballerina", *dragonfly-dancer*), half as unfamiliar (e.g., "antifurto"-"voce", *alarm-voice*).

Behavioral validation of familiarity for the metaphorical associations. To ensure that our intuitions concerning the distinction of familiarity were met, we ran a behavioral test with a group of 16 participants matched for age and education with the participants to the fMRI experiment. They were asked to complete a pencil-and-paper test evaluating the familiarity of the metaphorical associations (as presented in a copular sentence form) on a 3-point scale (familiar/unfamiliar/unsure). In addition, participants were asked to judge the emotional connotation of the sentences (positive/negative/uncertain). Metaphorical associations were considered validated when at least 80% of agreement on the classification of both familiarity and connotation was obtained.

Controlling for the main psycholinguistic variables. Taking into account the main psycholinguistic variables that are known to influence linguistic processing, we held a further selection process on the target nouns. We retained only those nouns that were concrete, countable and with a medium-to-high frequency, as evaluated both on a corpus and frequency lexicon of written Italian (CoLFIS; [9]) and on frequency ratings from 16 participants matched for age and education with the participants to the fMRI study. The validation returned a final set of 40 nouns, each paired with two other nouns (once literally and once metaphorically, with half of the metaphorical associations classified as familiar and half as unfamiliar), with a mean frequency of 56.23 (over 3.8 million occurrences), all rated as frequent by the judges. Frequency tended to be higher for the nouns that gave rise to familiar metaphors than for those that generated unfamiliar metaphors (75.75 and 36.7, respectively), although with no statistical difference between the two groups (two tailed paired t-test; $p = 0.16$). This tendency is consistent with the claim that word frequency is among the factors that contribute to metaphor frequency and, in turn, to metaphor familiarity.

Construction of the passage matrixes. Each noun pair was embedded into two-sentence passages. Two types of passages were created: one with minimal context and the other with a supportive cue in the linguistic context. Both types employed copular forms in the present tense, yielding nominal metaphors. For the minimal context type, we created simple question-answer passages, e.g., “Sai che cos'è quella ballerina? Una libellula” *Do you know what that dancer is? A dragonfly* (metaphorical condition) vs. “Sai che cos'è quell'insetto? Una libellula” *Do you know what that insect is? A dragonfly* (literal condition). For the supportive context type, we used two affirmative sentences, where the property bounding the noun and its associates, i.e., the so-called ground (e.g., “aggraziata”, *graceful*), was made explicit, e.g., “Quella ballerina è molto aggraziata. È una libellula” *That dancer is very graceful. (She) is a dragonfly* (metaphorical condition) vs. “Quell'insetto è molto aggraziato. È una libellula” *That insect is very graceful. (It) is a dragonfly* (literal condition). Approximately the same passage length was maintained across context types. A total of 40 passage pairs in the minimal context type and 40 passages pairs in the supportive context type were created. An equal number of filler passages (containing literal statements) were included for each context type, in order to limit the ratio between metaphorical and non-metaphorical items to 1:2 and to prevent enhancement of metaphor awareness (see Table 1).

Contextual expectancy evaluations. We ran a behavioral test in order to ensure that the degree of contextual expectancy varied between the two types of passage matrixes. We conducted a completion (‘cloze’) test in which we truncated all the experimental stimuli just before the target noun, and asked 29 Italian native speakers matched for age and education with the participants to the fMRI study to complete the text with the first word that comes to mind (15 participants were presented with passages of the minimal context type; 14 participants with passages of the supportive context type). Results of the cloze task confirmed our expectations, with an overall cloze probability of 0.09 for the minimal context type and 0.28 for the supportive context type. Cloze probability was low throughout the stimulus set, steadily below the 0.40 threshold.

fMRI task. In order to distract the participants from the actual goal of the experiment, we explained them that the purpose of the study was to evaluate how the brain associates sentences. We did not mention the presence of metaphors throughout the duration of the scanning sessions. In order to alert the participants' attention, they were asked to perform an adjective matching task. Following each passage, two adjectives were displayed, one on the left, the other on the right, one on-topic with respect to the passage, the other off-topic. Participants were given instructions to read each passage calmly and accurately, and then to make a judgment concerning which of the two adjectives better matched the previous passage by pressing a button in their right or left hand. Both passages in each pair (the one metaphorical and the other literal) were associated to a single adjective pair, so that the materials employed for the task were constant across conditions (e.g., for both the metaphorical and the literal passages built upon the noun “libellula” *dragonfly*, the adjective pair was “leggiadro” *fluid* vs. “croccante” *crispy*). Note that the correct adjectives were synonymous with the ground, i.e., the adjective used to bond the noun and its associates, that was made explicit in the supportive context condition (e.g., “leggiadro”, *fluid*, is synonymous of “aggraziata” *graceful*).

Debriefing. After scanning, a pencil-and-paper debriefing questionnaire was administered, aiming at ascertaining whether the participants had remained blind to the purpose of the study (i.e., unaware of the presence of metaphors) and evaluating the meta-linguistic ability to distinguish off-line between metaphorical and non-metaphorical expressions. First, we asked the participants to report their impressions about the aims of the study. Next, we explained the real purpose and asked whether they had somehow realized it. Finally, we presented a sample of the passages used in the scanning sessions, and asked to judge whether the passage was metaphorical or literal.

2.3. Procedures

Written stimuli were presented in lowercase white font on a dark background and projected onto a screen positioned on the top of the head coil that participants viewed through a mirror. The task sequence was controlled by a PC running *Presentation®* software (Neurobehavioral Systems Inc., Albany, CA). Each trial started with a fixation cross presented for a variable period (between 0 and 100 ms) in the centre of the screen, followed by the two-sentence passage for 3000 ms. This presentation time was chosen after consulting five native speakers of Italian. Then, the passage disappeared and was replaced by the adjective pair, with up to 2500 ms allocated for response. The buttons used to indicate the correct adjective (and the corresponding hand) were counterbalanced across participants. Reaction times (defined as the time between the onset of the adjectives and button pressing) and response accuracy were recorded. Thereafter, the screen remained blank until the next trial, resulting in a fixed total trial duration of 7500 ms.

The experiment used a fast-event related design in a randomized fashion. Each participant read a total of 120 two-sentence passages (40/conditions, i.e., literal, metaphorical and filler, equally distributed for familiarity and context type). The passages were divided in 4 runs (time series) of 30 passages each. An equal number of metaphors, literal and filler passages were contained in each run, with the only restriction that the members of each passage pair (the literal and the metaphorical versions of the same target noun) were assigned to distinct runs, in order to avoid long distance priming effects. Each run lasted a total of 300 s with a rest interval of 25 s in the middle of the run. After each run, there was a short break before the experimenter initiated the following session. The order of the passages within each run and the order of the four runs were randomized across participants. To enhance the performance, 6 practice trials including unpaired metaphorical and literal passages were administered before the acquisition of the fMRI data and were repeated as many times as needed to ensure that participants were familiar with the procedure. None of the passages presented during the practice trials was used in the fMRI experiment.

2.4. Image acquisition

Responses to metaphorical, literal and filler passages were measured using blood oxygen level dependent (BOLD) contrast fMRI with the acquisition of $T2^*$-weighted gradient echo planar images in a 1.5 T scanner (General Electric, Milwaukee, WI). In each time series, the whole brain volume was acquired 120 times, each volume consisting of 26 contiguous 5 mm thick axial slices (TR = 2500 ms, TE = 40 ms, flip angle 90, FOV = 24 cm resolution = 64×64 pixels). High-resolution T1-weighted spoiled gradient recall images (1.2 mm-thick axial slices, TR = 12.1 ms, TE = 5.22 ms, flip angle = 20°, FOV = 24 cm, resolution = 256×256 pixels) were obtained for each participant to provide detailed brain anatomy.

2.5. Data analysis

We used the AFNI package for the analysis (http://afni.nimh.nih.gov/afni, [27]). After volume registration, time and space normalization, data from each single run was concatenated and then smoothed (Gaussian-filter 8 mm FWHM). Image data were analyzed with multiple regression by using 60 regressors to model hemodynamic changes associated with the reading of each passage. In addition to these 60 regressors of interest, 6 regressors of no interest were included to factor out signal changes due to head motion correction post-processing analyses. After spatial normalization of each brain to the mean Talairach Atlas brain we performed

Table 1

Stimulus types. Original Italian passages and English translations are provided.[a]

	Metaphorical condition	Literal condition	Filler condition
Minimal context; familiar	Sai che cos'è quella ballerina? Una libellula. *Do you know what that dancer is? A dragonfly.*	Sai che cos'è quell'insetto? Una libellula. *Do you know what that insect is? A dragonfly.*	Sai che cos'è quel cane? Un barboncino. *Do you know what that dog is? A poodle.*
Minimal context; unfamiliar	Sai che cos'è quella voce? Un antifurto. *Do you know what that voice is? An alarm.*	Sai che cos'è quella sirena? Un antifurto. *Do you know what that siren is? An alarm.*	
Supportive context; familiar	Quella ballerina è molto aggraziata. È una libellula. *That dancer is very graceful. (She) is a dragonfly.*	Quell'insetto è molto aggraziato. È una libellula. *That insect is very graceful. (It) is a dragonfly.*	Quel liquore è molto forte. È una grappa. *That liqueur is very strong. (It) is a grappa.*
Supportive context; unfamiliar	Quella voce è molto stridula. È un antifurto. *That voice is very shrill. (It) is an alarm.*	Quella sirena è molto stridula. È un antifurto. *That siren is very shrill. (It) is an alarm.*	

[a] Note that the noun-adjective pairing is especially sensitive to translation issues: the English version of the passages might sound not perfectly felicitous, but the original Italian passages were judged as fully acceptable by native speakers.

a Two-Way mixed ANOVA (experimental conditions, as fixed factor; subjects, as random factor) to identify areas that differentially responded to metaphorical vs. non-metaphorical (literal and filler pooled together) passages. Successive post hoc two-tailed paired *t*-tests were applied to evaluate significant differences related to each condition. *t*-Tests are random effects tests in which each participant accounts for a single degree of freedom. The correction of the *T*-contrasts for multiple comparisons across whole brain was made using Monte-Carlo simulations run via AlphaSim in AFNI, and significant clusters were identified as contiguous voxels with $p < 0.005$ and a volume > 200 μl.

Within the metaphorical condition, two-tailed paired *t*-tests were applied to analyze the familiarity effect. Regions significantly activated for the contrast familiar vs. unfamiliar metaphors that overlap (logical AND) with regions significantly activated for the contrast metaphors vs. non-metaphors were used for the Region of Interest analysis of mean beta-weights. Significant clusters for the comparison metaphors vs. non-metaphors were defined as contiguous voxels with $p < 0.05$ (uncorrected) and a volume > 400 μl; similarly, for the comparison familiar vs. unfamiliar significant clusters were defined as contiguous voxels with $p < 0.05$ (uncorrected) and a volume > 400 μl. In these ROIs, a Repeated Measure ANOVA was applied to ascertain differences among unfamiliar metaphors, familiar metaphors, literal and filler passages. We set the statistical threshold at $p < 0.01$ for the ANOVA test, while differences in each possible pair of contrasts were considered significant with $p < 0.05$ (post hoc Sidak correction).

Likewise, two-tailed paired *t*-tests were performed to ascertain the effect of context type on the fMRI response to metaphors vs. non-metaphor. Regions significantly activated for the contrast metaphors in the minimal context vs. metaphor with supportive context that overlap with regions significantly activated for the contrast metaphors vs. non-metaphors were used for the Region of Interest analysis of the mean beta-weights. As described above, also in these ROIs we applied Repeated Measure ANOVA to ascertain differences among different types of passages across different contextual types.

3. Results

3.1. Behavioral results

Participants missed 1% of the answers on average, equally distributed across conditions. These cases were discarded from the analysis of both response times and accuracy.

Response times in the adjective matching task. The mean response times are shown in Table 2. We found no significant differences among passage types [F (2,590) = 0.903; $p = 0.406$]. Within the metaphorical condition, no significant differences were recorded between the average response time to familiar and unfamiliar metaphors, respectively 1263 ms (SD ± 349) and 1306 ms (SD ± 386) (two-tailed unpaired *t*-test; $p = 0.413$), and neither between the average response time to metaphors in the minimal context type and metaphors in the supportive context type, respectively 1315 ms (SD ± 360) and 1259 ms (SD ± 372) (two-tailed unpaired *t*-test; $p = 0.292$).

Accuracy in the adjective matching task. Percentages of correct responses are shown in Table 2. Participants were accurate in associating adjectives to previous passages, with no significant differences across conditions (Pearson Chi-square test; $\chi^2 = 0.559$; df = 2; $p = 0.756$). Within the metaphorical condition, analysis revealed no differences in the performance for familiar vs. unfamiliar metaphors, with a mean accuracy of 97.8% and 92.9%, respectively (Pearson Chi-square test; $\chi^2 = 2.499$; df = 1; $p = 0.114$) and neither for the minimal vs. supportive context types, with a mean accuracy of 94.3% and 96.6%, respectively (Pearson Chi-square test; $\chi^2 = 0.573$; df = 1; $p = 0.449$).

Table 2

Reaction times and accuracy in the adjective matching task. Shown are the mean reaction times (standard deviations in parentheses) and the mean percentages of correct responses (range in parentheses) to the metaphorical, literal and filler conditions.

Condition	Mean RT (ms)	Mean correct (%)
Metaphorical condition	1284 (367)	95.5 (84–100)
Literal condition	1328 (355)	96.1 (90–100)
Filler condition	1293 (323)	93.3 (60–100)

After-scan debriefing. In the post-scan pencil-and-paper questionnaire, participants were first required to express their impression about the aim of the study. Having been told that the study would concern word association, most participants answered re-elaborating the initial instructions they had been given, showing that they did not notice anything else beyond that. Then, when told that the purpose of the study was to investigate metaphor comprehension and asked whether they had noticed the presence of metaphors, seven out of nine participants declared to have remained blind to it throughout the duration of the experiment. Two participants (LD and AB) reported having noticed the presence of metaphorical expressions after the second half of the experimental session. Noteworthy, both of them had a robust background in humanities. Finally, when presented with a sample of stimuli, all participants were able to discriminate correctly between metaphorical and non-metaphorical passages, achieving greater than 95% accuracy for both types.

3.2. fMRI results

Activations for the three conditions (metaphorical, literal and filler passages) vs. rest are showed in Fig. 1 (Two-Way ANOVA; $p < 0.05$ uncorrected).

The comparison of metaphors with non-metaphors (literal and filler pooled together) showed significant clusters of activation in several regions (two-tailed paired *t*-tests; $p < 0.005$; cluster size corrected for multiple comparison; Table 3 and Fig. 2). Specifically, activations were observed in the frontal cortex bilaterally, namely in the pars triangularis of the inferior frontal gyrus (BA 45) in both hemispheres, in the pars orbitalis of the left inferior frontal gyrus (BA 47), in the right middle frontal gyrus (BA 9) and in the left superior frontal gyrus (BA 8). Activity extended bilaterally to the anterior insula. Significant response was also found in the right temporal cortex, specifically in the posterior superior temporal gyrus (BA 22), and in the left supramarginal/angular gyrus (BA 39/40). In addition, metaphor processing activated the anterior cingulate cortex bilaterally (left BA 24 and right BA 32) and the right cuneus (BA 18). No differences were observed between literal and filler passages.

In the Regions of Interest obtained through the overlap of the regions activated for the metaphor vs. non-metaphor contrast and those activated for the contrast between familiar and unfamiliar metaphors, higher activations for the unfamiliar metaphors as compared to all the other conditions (familiar metaphors, literal and filler passages) were observed along the superior temporal sulcus in both hemispheres, specifically in the left BA 21 and in the right BAs 21 and 22 (Repeated Measure ANOVA; $p < 0.01$; post hoc Sidak contrast; $p < 0.05$; Table 4 and Fig. 3). As for the modulation of context, the comparison of metaphors in minimal context with metaphors in supportive context was not significant in the pre-determined Regions of Interest.

4. Discussion

This study was designed to investigate the neural basis of metaphor comprehension while keeping processing as far as possible implicit and free from extra processing tasks. We were interested in identifying the neural correlates of metaphor comprehension in the perspective of disentangling the fundamental functional components that mediate such process in the brain based on predictions formulated along the pragmatic and cognitive literature. We also examined how these components are influenced by familiarity and by the presence vs. absence of a supportive linguistic context. The results showed that metaphor as compared to literal comprehension activates a diffuse neural network, extending bilaterally especially over fronto-temporal cortices, which can

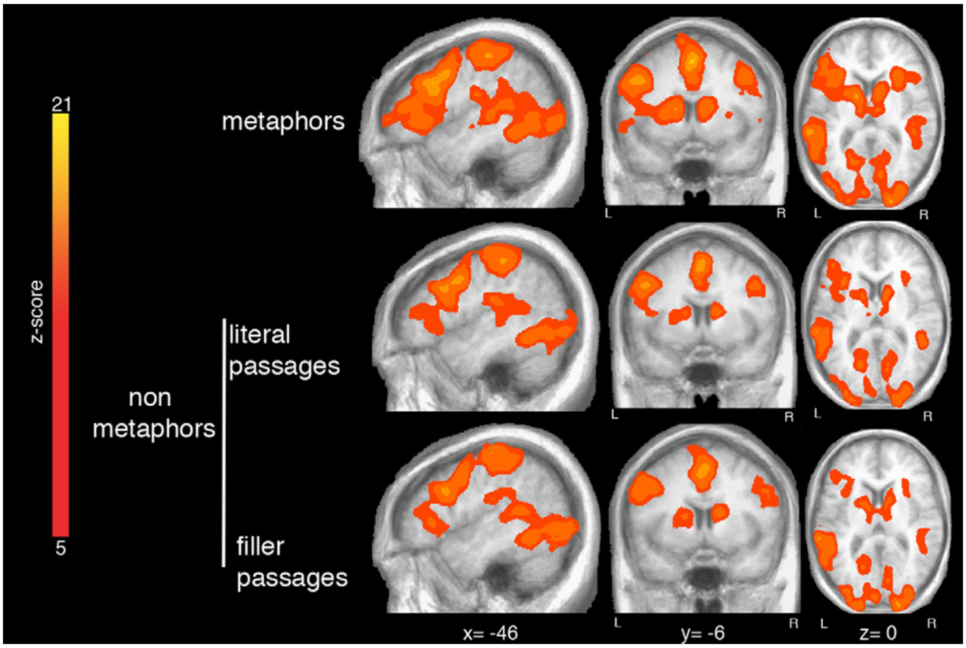

Fig. 1. Brain areas that responded during the three experimental conditions (metaphorical, literal and filler passages) as compared to the baseline rest condition ($p < 0.05$ uncorrected). Sagittal and axial images from spatially normalized *T* score group maps of activated areas are projected onto an across-subject brain template.

Table 3
Significant clusters of activation for the comparison metaphors vs. non-metaphors. $P < 0.005$ (cluster size corrected for multiple comparison). AC: anterior cingulate; IFG: inferior frontal gyrus; SFG: superior frontal gyrus; STG: superior temporal gyrus; MidFG: middle frontal gyrus; AG: angular gyrus.

Anatomical region	BA	Hemisphere	Volume	Peak (Tailarach coordinates)			*Z* score
				x	*y*	*z*	
AC	24	L	557	−4	11	29	3.443
AC	32	R	792	2	25	29	4.15
IFG	47	L	665	−49	20	−5	3.645
IFG/insula	45	L	563	−33	24	7	3.791
IFG/insula	45	R	1878	42	22	14	4.614
MidFG	9	R	1331	48	23	29	3.832
SFG	8	L	307	−1	32	51	3.655
STG	22	R	303	45	−25	4	3.29
AG	39/40	L	1147	−45	−42	24	4.421
Cuneus	18	R	977	10	−75	23	3.504

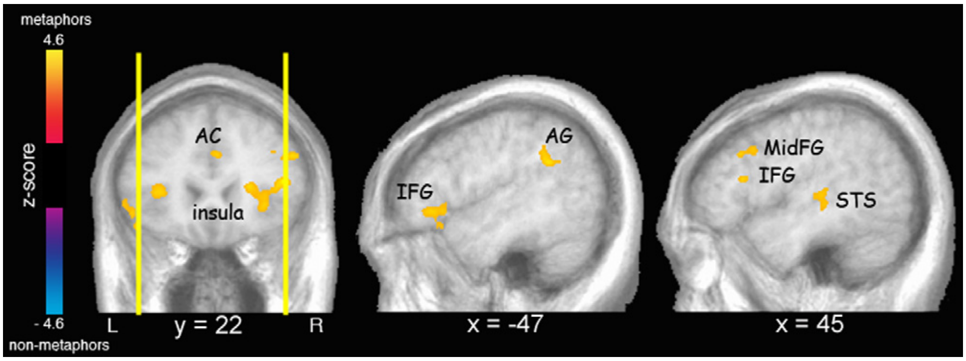

Fig. 2. Brain areas with higher activation for metaphors vs. non-metaphors (warm colors). $p < 0.005$ (cluster size corrected for multiple comparison). Coronal and sagittal images from spatially normalized *T*-score maps are projected onto an across-subject brain template. The yellow lines in the coronal image correspond to the locations of the sagittal slices. AC: anterior cingulate; IFG: inferior frontal gyrus; MidFG: middle frontal gyrus; STS: superior temporal sulcus; AG: angular gyrus. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

be correlated to a number of cognitive components as predicted by cognitive theorizing. Within this network, familiarity elicits the response of the regions along the bilateral superior temporal sulcus, while the manipulation of the linguistic context did not yield significant results. In the following, we first briefly comment on the behavioral results, suggesting that variations in BOLD activity are independent of concurrent cognitive operations related to the task and reflect the effect of metaphoricity in itself (Section 4.1). We then go on to discuss the fMRI data, by considering anatomo-functional correlations in relation to the hypotheses formulated in

Table 4
Conjunction analysis results for the comparison between metaphors vs. non-metaphors and familiar vs. unfamiliar ($p < 0.05$; cluster volume > 400 μL for both comparisons). MTG: middle temporal gyrus; STS: superior temporal sulcus.

Anatomical region	BA	Hemisphere	Volume	Peak (Tailarach coordinates)		
				x	*y*	*z*
MTG	21	L	460	−61	−28	−7
MTG	22	R	425	54	−35	−1
STS	21	L	369	−49	−11	−15
STS	21	R	211	43	−14	−6

the introduction (Section 4.2). A global glance at the network for metaphor comprehension is given is Section 4.3, with implications on the neuropsychological and theoretical side. Finally, we develop some considerations on the bilaterality issue, rejoining the debate over the role of the right hemisphere in pragmatics (Section 4.4).

4.1. Behavioral data

The adjective matching task was designed as to be performed after passage reading and to posit minimal cognitive load, possibly equal across conditions. As expected, no differences in response times nor in accuracy were observed between metaphorical and non-metaphorical passages. This piece of evidence suggests that variations in the fMRI data along metaphoricity are not due to different responses to the task. Furthermore, the overall high level of accuracy suggests that the cognitive load imposed by the task was minimal, and that the BOLD activity is likely to reflect task-free passage comprehension. Although we cannot exclude that the task projected backward on passage comprehension and produced a short term memory load, this effect should not have differed across conditions, and therefore should be eliminated in the subtraction. One may argue that metaphors may have not been fully understood, as high accuracy in adjective selection does not imply full understanding of the metaphors. The counter-objection is that we based the task on the so-called metaphor's ground, which required the communicated meaning of the sentence to be processed. Besides, there is evidence that speakers cannot ignore metaphorical meaning, including when they are asked to perform a task based on the literal meaning of metaphors [45]. Debriefing results lend thus further support to the idea that metaphors were recognized as such by the participants, although unknowingly.

4.2. Components of a functional network for metaphor comprehension

4.2.1. The conceptual component

Most of the activation clusters observed in our study are located bilaterally in the inferior frontal gyrus (IFG). Prefrontal activity

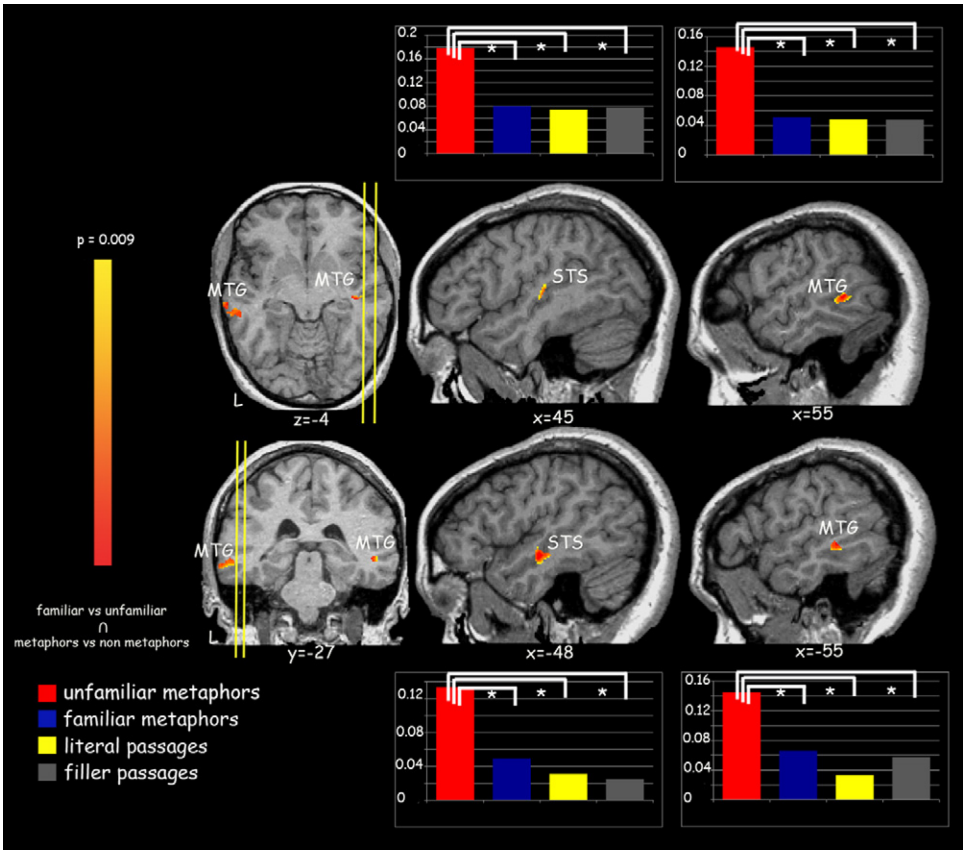

Fig. 3. Conjunction analysis results for the comparison between metaphors vs. non-metaphors and familiar vs. unfamiliar ($p < 0.05$; cluster volume > 400 μL for both comparisons). Axial and sagittal images from spatially normalized *T*-score maps are projected onto an across-subject brain template. The yellow lines in the axial images correspond to the locations of the sagittal slices. MTG: middle temporal gyrus; STS: superior temporal sulcus. Color bar indicates conjunct probability values. Bar graphs show the differential activations between unfamiliar metaphors (red) and all other conditions: familiar metaphors (blue), literal passages (yellow) and fillers (grey). $p < 0.05$ Sidak post hoc corrected. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

is certainly the most robust result in the metaphor literature, although with the usual debate between the right and the left hemisphere across studies. Limiting the observation to studies on non-conventional metaphors, one can find the following patterns: concurrent activation of left BAs 45 and 47 [57,91]; activity limited to left BA 47 [105] and to left BA 45 [98]; activity limited to right BA 45 [68,69,97]. Our results are consistent with this literature in pointing to the frontal areas, but, in contrast to it, reveal a bilateral pattern, specifically extending over left and right BA 45 and left BA 47. Below we will argue that this bifrontal pattern is likely to reflect the involvement of the conceptual system, activated in a context-sensitive mode, i.e., pragmatically, as postulated in the pragmatic and cognitive literature on metaphor and supported by a consistent body of fMRI evidence.

The involvement of the left IFG in searching, retrieving and integrating world knowledge into linguistic representations is well-known across the literature, where Broca's area and its vicinity have been repeatedly activated by world knowledge anomalies [49,59]. What is important in our perspective is that the left IFG is activated along with the right IFG. Increasing evidence in neuroscience of discourse is showing that the left IFG works in tandem with the right IFG when put to function in larger (beyond the single sentence) linguistic context [11,48]. A bifrontal network similar to the one observed here has already been described by Menenti et al. [74], where word meaning was to be integrated with world knowledge and local discourse context. The Authors used world knowledge correct and world knowledge anomalous sentences in neutral and non-neutral passages, with the latter passage type making the anomaly more acceptable (e.g., "With the lights on you can see more/less at night", embedded either in a discourse from drivers' point of view or from astronomers' point of view). They concluded that bilateral IFG regions are recruited for meaning unification of linguistic material and incoming information from knowledge stored in long term memory, with the difference that the right IFG is more specialized for discourse-scale updating with respect to the left part.

As far as metaphor is concerned, basing on this literature, we hypothesize that the bilateral IFG hosts the fine-tuning of lexical meaning, allowing for the integration of lexical representation and world knowledge in a given discourse context. Although generally nominal metaphors can also be interpreted with minimal linguistic context (as proved by the possibility of establishing metaphorical connections between two single words), they seem to elicit the construction of a plausible linguistic context: with respect to world knowledge anomalies, which cannot be worked out by the parser and elicit activations confined to the left IFG, metaphors are solved by prompting the construction of a plausible scenario, which results not simply in the meaning unification in the left IFG, but also in context updating in the right IFG. Metaphor posits a supplementary overload not in lexical access *per se*, but rather in the integration of lexical items with word knowledge, as well as in the construction of a context valid for that metaphor and compatible with background knowledge. In other words, the conceptual system is activated pragmatically, not merely semantically. Previous studies might have failed to reveal such a pattern due to stimulus design, not specifically attuned to unveil the additional demands over the conceptual system. Here, the choice of keeping the metaphors' vehicles constant, coupled with the use of passages, allowed us to focus on the pragmatic functioning of the conceptual system.

The idea that metaphor comprehension requires operations at the conceptual/pragmatic level seems to find further support in the activation of the left angular gyrus and the adjacent supramarginal gyrus. Activity in BA 39 has already been reported for metaphor [68,98], but has not found a precise interpretation besides being generically ascribed to the semantic system. Left BA 39 is usually activated along with frontal areas in tasks where semantic anomalies are embedded in sentence context [80, among others] and in discourse context [74]. In light of this evidence, the angular gyrus has recently been described as supporting meaning unification and integration [48,52] and in a position at the top of a processing hierarchy underlying concept retrieval and conceptual integration, specifically "fluent conceptual combination, such as sentence comprehension, discourse, problem solving, and planning" [10]. It seems to us that the hierarchically high role played by the angular gyrus in a number of semantic processes might capture the edge of the conceptual-pragmatic operations prompted by metaphor processing, i.e., the point where the construction of the metaphorical representation (the *ad hoc* concept, in Relevance Theory terms) is integrated and checked in context.

4.2.2. *The attentional component*

Another consistent cluster of activation is located in the anterior cingulate cortex (ACC), again bilaterally (BA 24 and BA 32). While the posterior part of the ACC is believed to be involved in emotional experience, the anterior division is traditionally assumed to host cognitive tasks, and especially attentive tasks [17]. Specifically, it has been activated by cognitively demanding tasks involving stimulus-response selection in the face of competing streams of information, including Color Stroop and Stroop-like tasks, divided-attention tasks, verbal and motor response selection tasks and many working memory tasks. The ACC has also been involved when the competing flows of information share the same representational format, as in the case of competing meanings in lexical ambiguities [21]. When it comes to metaphor, it is likely that alternative meanings are to be handled (to different degrees) and filtered on the basis of context in order to select and fine-tune the appropriate interpretation: the activations of competing meanings can be seen as part of the conceptual/pragmatic machinery described above.

Attentional mechanisms can also be connected to the activations recorded in bilateral superior and middle frontal gyrus (specifically right BA 9 and left BA 8). These areas are responsible for working memory [24] and are known to be involved in a variety of semantic tasks, especially when multiple and competing meanings are to be handled [71], also in tandem with the ACC [21]. A functional connectivity study on idiom comprehension by Romero Lauro et al. [94] pointed to the prominent role of these prefrontal areas in the attentional regulation when different interpretative hypotheses compete. The idea of an attentional load due to competing meanings has never been fully considered for metaphors at the neural level (but see [42] for a psycholinguistic account), probably because most of the fMRI studies employed high-demanding tasks, and attentional activity has mostly been interpreted in connection to the tasks. We suggest that attentional resources are needed in metaphor comprehension *per se* in order to support meaning selection, as part of the process of integrating lexical meaning and world knowledge in context, possibly recruiting the ACC and prefrontal areas. And indeed it has been said that the unification of meaning and word knowledge often implies selection, i.e., control [48]: along these lines, we cannot exclude that the conceptual processes taking place at the level of the IFG (especially the left portion) involve control as well.

Another possible interpretation worth consideration is that the activation of the anterior ACC reflects emotional processing. It has recently been argued that also that not only ventral-rostral but also dorsal-caudal portions of the cingulate cortex are involved in emotion [32]. The cognitive literature has pointed out that metaphorical expressions are related to emotion in many different ways: they are frequently used to describe emotional experiences [58] and they are likely to evoke aesthetic/emotional response [88]. Although our experiment was not explicitly built to disentangle the emotive component, the metaphors employed had a connotative valence (either positive or negative) and might have evoked a stronger emotional response in terms of aesthetic/poetic effects at the level of the ACC cortex as compared to the literal passages.

4.2.3. The Theory of Mind component and the effect of familiarity

We also reported activations in the right posterior superior temporal gyrus (STG), specifically in BA 22. This is compatible with a series of studies that ascribes much importance to the right homologue of Wernicke's area in solving metaphors, and especially in handling novelty, i.e., degrees of familiarity [67,69]. However, it remains unclear what novelty means for the brain in terms of cognitive component, and the specific functional system at stake in processing novelty is still to be determined.

One possibility is to interpret the greater activation in the right posterior STG for metaphors as compared to literal expressions in the same terms as the activity in the bilateral IFG, i.e., meaning unification in context, since the right STG has been shown to participate in semantic/pragmatic tasks [56,60]. Another option is that the stronger activation of the right posterior STG is related to a greater involvement of Theory of Mind mechanisms. Within the widely distributed system responsible for mind-reading, regions along the posterior superior temporal sulcus (STS) – including posterior STG – seem to be especially involved in monitoring the protagonists' perspective and attributing intentions to agents, bilaterally but with somewhat greater effect on the right [37,108]. For instance, Gallagher et al. [40] observed activity in the right posterior STS in response to understanding the meaning of stories and cartoons involving people. Pragmatic studies have suggested that the recognition of the speaker's meaning (in literal as in figurative uses of language) starts precisely from the recognition of other people' communicative intention, and this recognition is likely to be more effortful in case of non-literal uses of language with respect to literal uses and context being equal, requiring especially protagonist's perspective monitoring. Based on this evidence, we suggest that metaphor comprehension elicits Theory of Mind processing at the level of the right posterior STG.

The contrast between familiar and unfamiliar metaphors strengthens the hypothesis that the right posterior STG is related to mind-reading. In this comparison, several regions along the posterior STS responded significantly: not only BA 22 in the STG but also BA 21 in the middle temporal gyrus, and both bilaterally. Again, similar patterns of activations have been recorded for mentalizing tasks involving intention and perspective monitoring [19,72]. It seems thus that the involvement of the Theory of Mind system in metaphor comprehension varies along familiarity, involving a network of regions distributed along the bilateral STS, a network that seems to be more extensively activated by unfamiliar than by familiar metaphors.

4.2.4. Other activations

We also observed a higher activation for metaphor in bilateral anterior insula. Activity in the anterior insular areas has already been recorded in a number of studies on metaphor, including [69] for word pairs, and [1] and [97] for sentential forms. Schmidt and Seger [97] explained the role of the anterior insula in terms of enhancement of the integration between temporal lobes and frontal lobes, i.e., between lexical access and lexical selection. However, there are at least two other possible explanations. First, the insula has been shown to be involved in syntactic tasks [79]. Although the syntactic aspect of metaphor have never been investigated, it is possible that nominal metaphors posit a greater demand of syntactic processing (in addition to the conceptual one) if compared to literal copular sentences. Hints to this interpretation come from the theoretical syntax literature on copular sentences [31]. Second, the bilateral insula has been recently been described as an important area in verbal insight solution (as in the case of anagrams; see [4]). Insular activation may thus reflect a sort of "eureka effect" in solving metaphor, that is the moment where the search for appropriate meaning stops because the right balance of cognitive efforts and effects has been reached.

We also found increased activation in the right cuneus for metaphor when compared to non-metaphor. Activity in the visual cortex might indicate that metaphor comprehension has repercussions in terms of reading patterns, producing longer fixations. The eye-movement literature on figurative language is scant; there is, however, evidence that metonymies elicit longer second-pass times on critical region with respect to literal expressions [36], and so do conventionally metaphorical verbs [85]. Preliminary eye-movement data recorded on the same materials used in this study seem to confirm the second-pass effect [6].

4.3. A global glance at the functional network for metaphor comprehension

Overall, our results provide evidence for a diffuse network of brain activations that can be further decomposed into different sub-systems candidate to represent basic mechanisms of figurative language comprehension: the pragmatic functioning of the conceptual system in the bilateral IFG, familiarity-sensitive mind-reading operations along the STS (especially on the right side), attentional processes filtering various sources of information in the ACC and prefrontal cortex. Although our study has the limitation of the small number of subjects, we adopted stringent statistical thresholds, which, coupled with an extensive consideration of the available literature – both theoretical and neuroimaging, offered a consistent basis to hypothesize the cognitive decomposition as summarized above.

One point that deserves to be highlighted is that the functional network observed in our study is highly consistent with the body of clinical findings, both at a general and a specific level. At a general level, the network described here well matches the leading hypothesis in clinical pragmatics, i.e., that the underlying cause of pragmatic deficits, far from being unitary, finds different explanations in different populations [66,102]. If a network of cognitive functions for metaphor processing is acknowledged, then similar impairments at the behavioral level may be explained as caused by deficits in different parts of the network. At a specific level, each of the components identified here has been at times invoked for different clinical populations. Clinical pragmatics studies on patients with focal lesions, although frequently vague about the location of the damages, mostly concern frontal lobes [102], which is consistent with the pattern of activations discussed here in terms of bilateral IFG for conceptual/pragmatic system and attentional mechanisms in the prefrontal cortex. Difficulties experienced by schizophrenic patients may lie in the semantic-conceptual domain located in the left IFG, whose disruption leads to concretism [57]. Not to be excluded is that patients suffering from schizophrenia are deficitary in conceptual managing and integration due to working memory impairments at the level of the dorsolateral prefrontal cortex [61]. Our interpretation of bilateral ACC and prefrontal activations in terms of attentional processes finds support in the difficulties observed for Alzheimer patients in processing novel metaphors. While the neuropathological damage in the brain of patients with Alzheimer's disease preferentially involves the parietal and temporal lobes [86], prefrontal cortical areas may also be affected at some stages of the course of the disease [86,87,95]. Difficulties experienced by Alzheimer patients in comprehending metaphors correlate with low performances in memory and reasoning tasks, and have been explained in terms of poor executive functions in the prefrontal cortex [2]. Similarly, Monetta and Pell [78] postulated that metaphorical language impairments in Parkinson patients are probably due to a deficit in the fronto-striatal system for working memory. The involvement of the STS in service of Theory of Mind is confirmed by the case of autistic patients: their poor performance in metaphor comprehension has been explained in terms of deficits in first-order Theory of Mind [50]. Noteworthy, Norbury [81] highlights that another possible explanation is that autistic patients have a poor semantic-conceptual system: Theory of Mind seems to be a necessary but not sufficient component. In the large-scale network account, this statement can be further extended: all cognitive components of metaphor processing need to be intact to ensure comprehension.

Another important aspect related to the large-scale network account for metaphor is that the array of functions recruited is to be understood not as rigidly fixed but rather as modulated according to the type of metaphor and the specific contextual coordinates, with modulation resulting in different distributions of processing costs over the sub-systems and possibly in the recruitment of additional components. Here only the modulation along familiarity reached significance and involved the STS, while the modulation of linguistic context failed to show significant results. This negative evidence may be related to the small number of subjects, but also the minimal difference between the two passage types might have played a role: it is likely that – with a larger divergence between conditions and with a higher number of participants, brain activations for metaphors in supportive discourse would differ from those for metaphors in isolation. Other modulations can be postulated. Some metaphors might be grounded in bodily experience and might elicit a motor resonance: this hypothesis is supported by decades of cognitive theorizing [41,63] and by recent fMRI results on figurative action language [13,30]. Other metaphors might especially rely on imaginistic processes, recruiting the precuneus, which is frequently activated across the literature (see [68,97], among others), although not systematically probably due to discrepancies in the stimuli. Quite unexplored is the emotional import of some metaphors, and the probable involvement of the affective system, on which only a few hints have been given here concerning the ACC. Not to be neglected is the ubiquitous nature of metaphor across the linguistic structure, which is likely to provoke different effects in neural terms, as noted in [96]: consider for instance the case of metaphorically used verbs – the so-called fictive motion verbs, which seems to elicit spatial perceptual processing [22].

As a final consideration, after having mapped brain activity in connection to cognitive theorizing, it is worth trying to go backwards, i.e., from brain mapping to cognitive modeling. Do the available data allow us to discriminate among the existing theoretical accounts? All models of metaphor comprehension agree in postulating the involvement of the conceptual system, a hypothesis that is confirmed by our results. The aspect where models differ is the description of the type of operations occurring in the conceptual system, ranging from *ad hoc* concepts construction via context-driven inferential operations (Relevance Theory) to association and blending (Cognitive Linguistics). It is not possible – at this stage and with this protocol – to ascribe the activations occurring in the conceptual system to either type. Inference and association are – to use Marr's terms – algorithmic notions still difficult to decline in implementation ('neuro') terms. Moreover, it is possible that inference and association capture different yet not incompatible aspects of the metaphor comprehension process [106,109]. What can be said is that, overall, our experimental results highlight an array of components supporting the conceptual-pragmatic machinery, which goes very well in the direction of an account of metaphor processing not limited to the conceptual dimension. To this respect, Relevance Theory seems to offer the most complete framework for understanding figurative language comprehension: not only it invokes the conceptual-inferential processes, but it also assumes that the appreciation of metaphor is first of all prompted by the recognition of the speaker's communicative intentions and crucially relies on mind-reading mechanisms, and unfolds in the focus of attention with a constant monitoring of contextual elements [99]. The other models, to our knowledge, still need to be worked out in order to fit the complex interplay of functions engendered by metaphor.

4.4. Hemispheric predominance for metaphor processing and pragmatics revised

The inspection of our results suggests that the main difference between literal and metaphorical processing is not a shift from left to right activation, but presumably an extension of activations, without suppressing the left hemisphere contribution. This extension results in a bilateral configuration, where each sub-system (the conceptual, the mind-reading, the attentional) seems to spread on both hemispheres. Two basic facts need to be emphasized.

First, that language activation limited to a single hemisphere is rarely observed when it comes to language in context. The emerging body of evidence that goes under the label of neuropragmatics is revealing the concurrent activity of both hemispheres whenever the task is to derive contextually appropriate meaning [5,102]. Moreover, also for the structural components of language, most of the experiments on right-handed participants show bilateral activations, with a weak (or even without) left-greater-than-right asymmetry (see [29] for a qualitative synopsis comparing left and right activations and [10] for a meta-analysis on the semantic domain). The involvement of the right hemisphere is thus not a specificity of metaphor or pragmatics, but it is part of 'normal' language processing [65,103].

Second, we do not rule out the possibility that the right hemisphere has somehow different capabilities with respect to the left. A widely agreed upon hypothesis assumes that the left hemisphere performs relatively finer coding of semantic information, which is extremely efficient for literal language comprehension; whereas the right hemisphere performs relatively coarser coding of semantic information, which is especially useful for discourse and pragmatics, when semantic integration becomes more difficult [55; see also 84 for a discussion on idioms]. The idea that hemisphere matters has found large adhesion across the literature on figurative language and discourse processing [62]. Far from denying any specificity of the right hemisphere, here we emphasize that the two hemispheres work in tandem. Perhaps metaphor is a matter of coarse grain processing in the right hemisphere, which – either inferentially or associatively – connects elements, but, if so, the coarse grain processing happens along with a different kind of processing (possibly finer) in the left hemisphere. Similar considerations hold for other high-level functions, such as insight solution, which is likely not to be a matter of *Gestalt* processing in the right hemisphere alone, but rather to result from the conjunction of this strategy with serial processing happening in the left hemisphere [4]. Furthermore, it is possible that, within a bilateral pattern, the two hemispheres operate on different strategies at different times, as suggested by recent neurophysiological research [34]. Exploring the when and how of interhemispheric cooperation seems to be a very promising research line, rather than simply disputing over where between the two hemispheres.

A final important consideration following from the two points mentioned above is that bilateral patterns of brain activity partially overlapping to our results have been observed for other pragmatic phenomena, and have been decomposed similarly. Recruiting world knowledge in discourse, interpreting jokes, comprehending idioms, all seem to recruit IFG for conceptual processing, prefrontal cortex for attentional operations and in many cases portions of the Theory of Mind network (for a review, see [35]). Also more general models of language comprehension postulate the interplay of meaning unification and control, as already mentioned in the discussion on the attentional component [47,48]. Finding regularities in how the brain manages language in use in general and integrates different contextual elements in order to bridge the gap between linguistic meaning and communicated meaning seems to be the paramount challenge, and metaphor represents a crucial test-bed. The reason for the discrepancy in the existing literature may precisely lie in the rich yet still vague definition of context.

5. Conclusions

The results of the fMRI experiment allowed us to move beyond the right hemisphere hypothesis, and to break down the process of metaphor comprehension into a set of cognitive resources bilaterally distributed over a network of brain regions. Our proposal represents a cognitive decomposition rather than a proper model, and points to the orchestration of various sub-systems, among which a crucial role seems to be played by the conceptual/pragmatics interface, Theory of Mind, and attentional resources. These sub-systems stand as the most plausible candidates to produce pragmatic impairments in specific pathological conditions. Our cognitive decomposition represents the first step toward a full neurofunctional model of metaphor comprehension, possibly a deflationary one, in line with the proposal by Sperber and Wilson [101]. Being not an abuse or a misuse but just one – although very powerful – possible use of language [28], metaphor probably needs not a more specific model, but rather a broader one, attuned to characterize the functioning (and the disruption) of language in context in general.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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